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Water Availability Analysis: Case Study of Lift Irrigation Scheme

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ABSTRACT: Water availability is the main & the most important parameter for the success of any water Resources Project. By means of analysis of hydrologic data through statistical techniques one can arrive at appropriate value of water availability in the reservoir. The present paper discusses the water availability & reliability for a lift irrigation scheme, where water is lifted from river Krishna in rainy season. And water from a reservoir, Shivajisagar is demanded as and when required. Water from Krishna river is lifted at Mhaisai Kolhapur Type (K.T.) weir in rainy season with the available discharge. Based on the data, discharge values are examined for existence of persistence, randomness, consistency. Also 75% & 90% dependable values are estimated. Autoregressive model is fit. Analysis shows existence of persistence, randomness, consistency of the data. This will help assess water availability & its reliability.

KEYWORDS: Water Availability, synthetic generation, randomness, Autoregressive model,

I. INTRODUCTION

One of the major economic bases of the country India is agriculture. In order to increase the agriculture yield, artificial, timely application of water to crops is required. The application of water depends largely on the implementation of various irrigation projects. Water is a finite resource and water resources planning is very important. The most important aspect is to study the water availability for the project, may be gravity flow Irrigation Projects or Lift Irrigation Schemes. The basics of this needs scientific analysis. While planning for Water Resources Projects, one has to estimate availability of water in terms of annual totals, average or dependable value based on historical data. It is not generally possible to determine the exact sequence of hydrologic events for which the project must be designed. Consideration has to be given to all possible combinations of sequences or series of hydrologic events that can occur. The Water Availability Study for all types of Water Resources Projects, including L I Schemes is a prerequisite for designing.

II. RELATED WORK

Planning of water resources projects based on scientific data in respect of present water availability & forecasting its future behaviour is one of the important factors of water management. A mathematical / stochastic model for monthly river inflow is a useful tool for generation of synthetic data. Sh.Arun & Sh.Neeraj in their article on Stochastic Modelling of Mahi River inflows, mention that the problem of short term river inflow forecasting is of considerable practical importance. Dam construction, reservoir operation, flood control are a few situations where future knowledge of river inflows will improve management of water resources [1]. On the same lines when river water from barrages / K.T.Weirs is to be lifted directly, the future predictions are required. So that especially for Lift Irrigation Schemes, it becomes easier to decide as to when & how much water can be lifted at higher elevation.

Sh. A. Kote & V. Jothiprakash in their paper on Reservoir inflow Prediction Using time lagged Recurrent Neural Networks, mention that inflow data for longer length at reservoir site is necessary for proper planning [2]. Presently, measured length of inflow data is insufficient for use in planning & operation. Applicability of non linear model based on artificial neural network with a random component embedded is explored for Pawana reservoir in upper Bhima river

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basin, Maharashtra, India. Large number of time series models with varying complexities for inflow predictions are available [3]. It is assumed that the synthetic flow should resemble the historical series.

Lift Irrigation Schemes in Maharashtra

Monsoon in Maharashtra i.e. rainy days are only for a period of four months. Storing the rain water in these 4 months by constructing dams & using water throughout the year for irrigation was the procedure followed. With undulating topography, there is limitation to supply water by gravity flow at high level altitudes. Hence benefit of irrigation to all area is not possible. The irrigation in Maharashtra till 1973, was basically through construction of Irrigation projects i.e. Dams, canal networks, water was supplied through gravity flow.

In the year 1972, during severe drought lift irrigations on cooperative basis, small scale lift Irrigation Schemes were taken up.

III. THE CASE STUDY

The main objectives of the study w.r.t LIS are, to;

- Examine the record of river discharge values for existence of persistence.
- Find out if the sequence of river discharge values are random
- Examine river discharge data for consistency.
- Estimate the 75% & 90% dependable value of discharge wise & also overall considering period from 2008 to 2015
- Fit Autoregressive models to generate synthetic sequences of river discharge.

About Mhaisai Scheme.

In the Sangli district in Maharashtra, rainfall reduces from western side to eastern. The rainfall in Sangli & Solapur is uneven, scanty, spread over thinly and not reliable also. The talukas, Jat, Sangola, Mangalaveda are at 600 to 750 feet higher elevation from Krishna River. People in this area are dependent on rains only. Annual rainfall in this area is very less around 300mm to 500mm. Practically, no big dams can be constructed in these areas to give gravity flow irrigation facility.

Hence if the farmer in this area is to be provided with irrigation facility it has to be through lift irrigation. The western part of Sangli receives rainfall in plenty. The river Krishna flows with its fullest capacity. In view of supplying water for the drought prone areas, Lift irrigation projects are the only possible solution. In view of this Krishna –Koyana Lift Irrigation Schemes were taken up. Mhaisai is one of the major LI projects taken up. The salient features of Mhaisai Lift Irrigation Project are given below.

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Salient Features

Sr. No.	Attribute	Particulars
1	Irrigation Project Name	Mhaisal Lift Irrigation Project
2	Purpose of Project	Irrigation
3	Planning of project.	To lift the water from Krishna river at Mhaisal Tal. Miraj, Dist. Sangli to irrigate 81697 Ha. of area in Miraj, Kavathemahakal, Jath & Sangol Talukas of Sangli district and Sangol, Magalawedha Talukas of Solapur district as 66550 Ha. equivalent area by tank filling in Jath, Sangol, Magalawedha Talukas.
4	Water Availability & utilization.	In Kharif season, 5860 Mcft (5.86 TMC) of water will be available from runoff of the river Krishna & in fair weather season, from Koyna reservoir, 11580 Mcft. (11.58 TMC). Annual utilization 17.44 TMC
5	Culturable Command Area (CCA)	128112 Hectare
6	Irrigation Potential	81697 Hectare
7	Project covered under DPAP	Yes

The Mhaisal LIS gets water from two sources, the Krishna River Discharge during monsoon season and releases from Shivajisagar (Koyna Reservoir) after monsoon, as & when demanded.

The data under consideration is the average discharges during rainy days of monsoon season for the years from 2008 to 2015. The lifting point is Mhaisal K.T. Weir near Shirol.

The estimation of water availability requires application of statistical techniques. Sequential generation hydrologic information is a statistical process. The synthetic sequences of river discharge, at one particular site have following steps.

1. Examination of record to determine existence of persistence.

The degree to which the discharge in any one year is dependent upon the magnitude of discharge in the years preceding it. Lag one serial correlation coefficient, viz 'r₁' describes the strength of relation between a value in the sequence and that preceding it by one time interval (hence lag one). For strictly random sequences, the value of 'r₁' necessarily differs from zero only by sampling variation. For sequences, showing strong persistence, its value is close to one.

If the data sequence is denoted by (y_t)_{t=1,2,...,N}, the lag one serial correlation coefficient 'r₁' is calculated as follows.

i. Calculate the arithmetic mean $\bar{y} = \sum_{t=1}^N (y_t) / N$

ii. Calculate C₁ (serial covariance of lag 1)

$$C_1 = \sum_{t=1}^{N-1} ((y_t - \bar{y})(y_{t+1} - \bar{y})) / N$$

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iii. Calculate C_0 (serial covariance of lag zero)

$$C_0 = \frac{\sum_{t=1}^N (y_t - \bar{y})^2}{N}$$

iv. Calculate ' r_1 ' given by $r_1 = C_1/C_0$ lag one serial correlation coefficient.

The concept of lag one serial correlation can be easily generalised to give the lag K serial correlation coefficient denoted by ' r_k ' given by

$$C_k = \frac{\sum_{t=1}^{N-k} ((y_t - \bar{y})(y_{t+k} - \bar{y}))}{N}$$

2. Exact test for the lag one serial correlation coefficient.

If r_1 is defined as,

$$r_1 = \frac{\sum_{t=1}^{N-1} [(1/(N-1)) \sum_{t=1}^{N-1} (y_t - \bar{y})(y_{t+1} - \bar{y})]}{\sum_{t=1}^N (y_t - \bar{y})^2 / N}$$

r_1 is distributed Normally with mean $-1/(N-1)$ with variance $(N-2)^2 / (N-1)^3$ if r_1 lies outside the range

$$\left[-\frac{1}{N-1} + \frac{1.96 \cdot (N-2)}{(N-1)^{3/2}}, -\frac{1}{N-1} - \frac{1.96 \cdot (N-2)}{(N-1)^{3/2}} \right]$$

then there is evidence that r_1 is significantly different from zero,

The data of river discharges in cusecs, at Ankali bridge are collected. The data available for monsoon months viz. June to October only are analysed. Water for the irrigation is lifted at Mhaisal K.T. weir. The table below gives statistical constants, viz. Average/ mean discharge, the standard deviation, dependable values. It is common practice to use dependable values estimated using Weibull's formula. Lag one & lag two serial correlation coefficients are estimated and are examined if they between the upper & lower limits as mentioned.

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Average discharge values in cusecs (Cubic feet per second) at Ankali Bridge, a river gauge station on river Krishna.

1. The constants estimated using Average river Discharge [in cusecs]

Particulars	2008	2009	2010	2011	2012	2013	2014	2015
Total number of rainy days.	105	95	107	134	142	152	151	139
Average	20906.49	21298.34	21572.76	22935.1381	14454.85	21845.73355	16186.46358	5267.752
Max	118761	70570	83739	167440	54707.5	126642	89127	53365.5
Min	25	4945	5006	650	400	150	240	24
Std. Dev P	27252.264	15155.03	17539.94	28589.8171	13225.77	30913.7378	21873.61729	7185.985
Std. Dev.S	29788.384	15235.43	17970.74	28697.0963	13272.59	31023.1673	21413.60271	7092.555

2. Dependable value

Year	60%	75%	90%
2008	9994.14	6390	2221.66
2009	15260	10170	7530
2010	12275	10170	6974
2011	8260	6777	1638
2012	6924	2973	1137
2013	5767	2479	1086
2014	5662	1420	500
2015	2463	889.5	300
Average	8325.6425	5158.563	2673.333

3. Existence of persistence and consistency (randomness)

$$\text{Average} = \bar{Y} = \sum_{i=1}^8 Y_i / N = 18058.44 \text{ Cusecs}$$

a. C_1 (serial covariance of lag 1) is $C_1 = \sum_{i=1}^7 \frac{(Y_i - \bar{Y})(Y_{i+1} - \bar{Y})}{N} = 2923049.754$	b. C_2 (serial covariance of lag 1) $C_2 = \sum_{i=1}^6 \frac{(Y_i - \bar{Y})(Y_{i+2} - \bar{Y})}{N} = -1260243.24$
c. C_0 (serial covariance of lag zero) $C_0 = \sum_{i=1}^8 \frac{(Y_i - \bar{Y})^2}{N} = 31147050.46$	Lag one serial correlation coefficient = r_1 $r_1 = C_1 / C_0 = 0.093846$ Lag two serial correlation coefficient = r_2 $r_2 = C_2 / C_0 = -0.04046$
$r_1 = 0.0938$ and $r_2 = -0.04$, lie between 0.49212 & -0.77783, within the range, Hence the data are consistent with the hypothesis of randomness. $\{[-1/((N-1))+1.96*(N-2)/(N-1)^{1.5}, \quad [-1/((N-1))-1.96*(N-2)/(N-1)^{1.5}]$ $= 0.492123 \quad = -0.77783$	

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3. The generation of synthetic sequences of discharges in cusecs in rainy season, with presence of persistence.

For the data of the discharges at Anklibridge, Autoregressive models are fit as given below.

Autoregressive models:.

The equation given below is termed as k-order autoregression.

$$(y_i - \mu) = \beta_1 (y_{i-1} - \mu) + \beta_2 (y_{i-2} - \mu) + \dots + \beta_k (y_{i-k} - \mu) + \epsilon_i$$

The random variates ϵ_i are usually assumed to be normally & independently distributed with zero mean and variance σ_i^2 . In addition to determine the order k of autoregression required to describe the persistence adequately, it is necessary to estimate k+2 parameters;

$\beta_1, \beta_2, \dots, \beta_k, \mu$ and the variance σ_i^2 of residuals.

The first order autoregression

$$(y_i - \mu) = \beta_1 (y_{i-1} - \mu) + \epsilon_i$$

has found particular application in hydrology

When μ, β_1 and σ_1^2 have been estimated, the sequence of synthetic values can be generated with the help of equation

$$y_1 = \mu + \beta_1 (y_0 - \mu) + \epsilon_1 \quad \text{-----(a)}$$

$$y_2 = \mu + \beta_1 (y_1 - \mu) + \epsilon_2$$

.....
.....

Assume a particular value, y_0 = average value, say to start the sequence, and if we have available a table of random normal deviates to give a sequence of variate values $\epsilon_1, \epsilon_2, \epsilon_3, \dots$ drawn from a normal distribution with zero mean & variance σ_ϵ^2 .

Where, r_1 lag one serial correlation coefficient is estimate of β_1 , $\bar{y}$, mean is estimate of μ , and so on. Equations (a) give a generated sequence $(y_1, y_2, y_3, \dots)$ having statistical properties resembling those of the sequence of observed discharge.

For the data of river discharges, first & second order Auto regressive models have been fit.

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Generation of Synthetic Sequences of river discharge

Sr. No.	Year	Average Discharge [in cusecs]	(Yi - $\bar{Y}$)	For C ₀ [(Yi - $\bar{Y}$) ²]/8	For C ₁ [(Yi - $\bar{Y}$)(Yi+1 - $\bar{Y}$)]/8	For C ₂ [(Yi - $\bar{Y}$)(Yi+2 - $\bar{Y}$)]/8	[(Yi - $\bar{Y}$) ²]/5
		$\bar{Y}$					
1	2008	20906.49	2848.05	1013923.94	1153425.59	1251119.03	1622278.303
2	2009	21298.34	3239.90	1312120.71	1423255.38	1975003.04	2099393.13
3	2010	21572.76	3514.32	1543803.01	2142282.87	-1583018.78	2470084.808
4	2011	22935.14	4876.70	2972773.00	-2196701.26	2308685.89	4756436.793
5	2012	14454.85	-3603.59	1623230.71	-1705980.65	843228.95	2597169.132
6	2013	21845.73	3787.29	1792949.06	-886215.53	-6055261.37	2868718.491
7	2014	16186.46	-1871.98	438036.97	2992983.34		700859.1463
8	2015	5267.75	-12790.69	20450213.08			32720340.93
Average =		18058.44109	0	31147050.46	2923049.755	-1260243.242	49835280.74

First order Autoregressive model is

$$(Y_i - \bar{Y}) = \beta_1^* (Y_{i-1} - \bar{Y}) + \epsilon_i \quad \text{where variance of } \epsilon_i \text{ is } = s^2$$

r_1 is estimate of β_1

$$Y_i = r_1^* (Y_{i-1} - \bar{Y}) + \epsilon_i$$

First order Auto regression. Estimation of μ , β_1 and σ_{ϵ}^2

$$\bar{Y} = \sum_{i=1}^8 Y_i / N = 18058.4411 \text{ Cusecs}$$

$\bar{Y}$ is estimate of μ ,

$$r_1 = C_1 / C_0 = 0.0938 \quad r_2 = C_2 / C_0 = -0.04046$$

= estimate of β_1 = estimate of β_2

$r_1 = 0.0938$ which lies between 0.49212 & -0.77783, within the range, the data are

$$\{[-1/((N-1))] + 1.96^*(N-2)/(N-1)^{1.5}, \quad [-1/((N-1))] - 1.96^*(N-2)/(N-1)^{1.5}\}$$

$$= 0.49212317 \quad = -0.777837458$$

$$s^2 = \frac{N-1}{N} (1-r_1^2) \sum \frac{(Y_i - \bar{Y})^2}{(N-3)} = (7/8) * (1 - (0.09385)^2) * (49835280.74) = 43221797.88$$

s^2 is the estimate of $\epsilon_i (\sigma_{\epsilon}^2)$

$$\hat{\beta}_1 = r_1(1-r_2)/(1-r_1^2) = (0.09385)(1-(-0.0405))/(1-0.09385^2) = 0.09851866$$

$$\hat{\beta}_2 = (r_2 - r_1^2)/(1-r_1^2) = (-0.0405 - (0.09385)^2)/(1-0.09385^2) = -0.049745976$$

$$\sigma_{\epsilon}^2 = ((N-2)/(N-5)) * (C_0 - \beta_1^* C_1 - \beta_2^* C_2)$$

$$= (6/3) * (31147050.46 - 0.0985186 * 2923049.754 - (-0.049745976) * (-1260243.2422))$$

$$= 61592767.3$$

First order Autoregressive model is

$$(Y_i - \bar{Y}) = \beta_1^* (Y_{i-1} - \bar{Y}) + \epsilon_i \quad \text{where variance of } \epsilon_i \text{ is } = 43221797.88 = s^2$$

$$Y_i = \bar{Y} + r_1^* (Y_{i-1} - \bar{Y}) + \epsilon_i \quad r_1 \text{ is estimate of } \beta_1$$

$$Y_i = 18058.44 + r_1^* (Y_{i-1} - \bar{Y}) + \epsilon_i = 18058.44 + 0.09384676^* (Y_{i-1} - 18058.44) + \epsilon_i$$

$$Y_i = 18058.44 + 0.09384676^* Y_{i-1} - 0.09384676^* 18058.44 + \epsilon_i$$

$$Y_i = 0.09384676^* Y_{i-1} - 1694.726085 + 18058.44$$

$$Y_i = 0.09384676^* Y_{i-1} + 16363.71$$

Second order Autoregressive model is i=2;

$$(Y_i - \bar{Y}) = \beta_1^* (Y_{i-1} - \bar{Y}) + \beta_2^* (Y_{i-2} - \bar{Y}) + \epsilon_i$$

$$Y_2 = 18058.4^* (1 + 0.09852 - 0.04975) + 0.09852 Y_1 + 0.04975 Y_0$$

$$Y_2 = +0.09852 Y_1 + 0.04975 Y_0 + 18939.1$$

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IV. CONCLUSION

Based on the applications of statistical techniques, it can be concluded that;

- The river discharge values have existence of persistence.
- The sequence of river discharge values are random
- The river discharge values are consistent.
- The 75% & 90% dependable value of discharges range from 889.5 to 10170 and 300 to 7530 respectively, in a period from 2008 to 2015. Average discharges are 5158.56 cusecs & 2673.33 cusecs with 75% & 90% dependability. This very much satisfies water requirement during monsoon season. Considering discharge in river, more quantum of lifting of water is possible
- Autoregressive models of order one & two are fit to generate synthetic sequences of river discharge.

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